NASA Kennedy Space Center OSSI/NIFS Intern
Research Report
July 22nd, 2016

LED Lighting and Plant Growth: Supplemental LED Effects on Development

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I. Abstract

The growth of plants aboard the International Space Station (ISS) will play a pivotal role in advancing human space exploration to further uncharted destinations. Not only will plants be useful for oxygen production and carbon dioxide reduction, they will also serve as a supplemental food source for the astronaut diet. Research indicates that the most efficient way for these crops to be grown is by using electric lighting – specifically light-emitting diodes (LED) due to their several unique advantages. One of these advantages includes the potential for selecting certain wavelengths. By isolating certain lights, the effects of specific wavelengths on plant growth can be made clearer. This research project examined plant morphology, chlorophyll, biomass production, and nutrient synthesis in 'Outredgeous' red romaine lettuce grown under six LED light treatments of white (W), W + blue (B), W + green (G), W + red (R), W + far red (FR), and a Heliospectra lamp (Helio) (-composed of B+G+R+FR LEDs without W LEDS-). It was consistently found that the lettuce grown under the Helio, W + FR, W + R, and W + G treatments all showed improved physiology in terms of shoot length, shoot diameter, fresh mass, and dry mass relative to the W control. The Helio, W + FR, and W + G treatments exhibited significantly larger leaf areas while the Helio and W + FR treatments also produced more leaves on average at 28 days after planting (DAP). The W (control) and W + B treatments showed the highest accumulation of chlorophyll at 28 DAP. In conclusion, lettuce grown under the Helio treatment may be the overall most beneficial for supplementing the astronaut diet in terms of total edible biomass produced in a 28 day crop cycle.

II. Background

LED lights provide many advantages in comparison to other electric lighting such as its practical ability for one to control the wavelength of light emitted, its light weight and small size, reduced heating, and longevity (Lin *et al*, 2012). In comparison to high pressure sodium, metal-halide, and incandescent lamps, LED lights are much less hazardous and do not provide unnecessary wavelengths outside of the spectrum usable for photosynthesis in plants (Lin *et al*, 2012). The red and blue lights are especially useful in driving photosynthesis since chlorophyll and carotenoids have high absorptions at wavelengths respective to that of blue and red (ibid).

Lettuce (*Lactuca sativa*) is an ideal crop for this experiment due to its relatively fast growth rate and its visible sensitivity to different wavelengths of light, which is perfect for helping to determine which wavelengths of light are optimal for plant growth and nutrient production needed to sustain the crew aboard the ISS.

Although green light is only weakly absorbed by chlorophyll and carotenoid pigments, according to previous research, green light can actually induce stem elongation and plant growth with enough intensity (Johkan *et al*, 2011). It is also seems to be that green light in combination with red and blue light as well as fluorescent light (FL), often used as a control, promotes improved plant growth (Kim *et al*, 2004).

III. Materials and Methods

Outredgeous Red Romaine lettuce was grown in growth chambers each under their own specific light. Lettuce seeds were planted in 10 different plastic square pots containing arcillite media with Nutricote fertilizer (not hydroponic). In order to eliminate error due to edge and position effects, the pots were rotated every other day such as pointed out in Kim *et al*, 2004. The treatments were thinned every 7 days where one plant was extracted from each pot every 7, 14, 21, and 28 days after planting (DAP).

Moreover, the photosynthetic photon flux (PPF) levels were maintained at an average of ~180 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ throughout the entire canopy by adjusting the heights of all LED lamps weekly. The YPF levels were balanced so that all LED treatment combinations were providing equal light levels. During each harvest (every 7 days), specific techniques and tools were used to measure total biomass accumulation, morphology, chlorophyll content, and nutrient content. Results were evaluated to determine the effects that each monochromatic wavelength has on the growth of the crop. The most optimal lighting conditions for the health and nutrient performance of the plant were determined.

IV. Results

Morphology

As shown in Fig. 1, the leaf area for the Helio spectra shows the greatest average area at 28 DAP followed by W + R, W + FR, W + G, W + B, and W (control). Helio is significantly different ($p < 0.0001$) from W (control). W + R is also very statistically significant (**) from W (control). Differences in W + G leaf area compared to W (control) was also statistically significant. When considering leaf number, the Helio treatment had the largest leaf area at 28 DAP followed by W + R, W + FR, W + G, W + B, and W (control), as can be seen in Fig 2. The Helio and W + FR are the only two significantly different from the white control, the Helio being extremely significant (***).

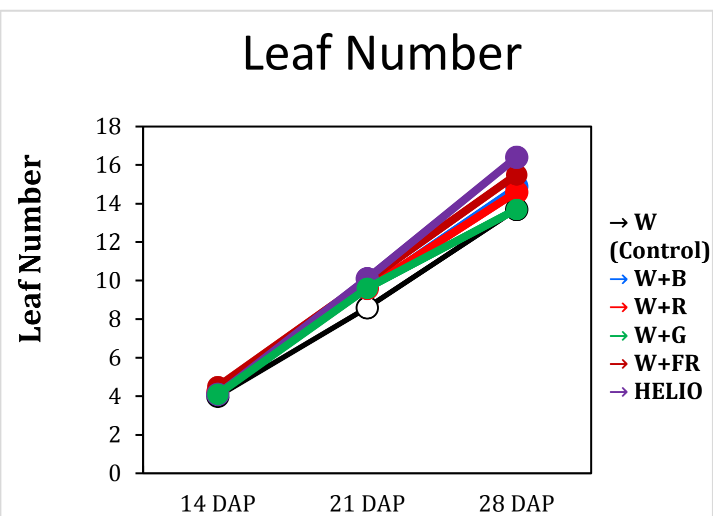


Fig. 1. Leaf number for all treatments for 14, 21,and 28 DAP.

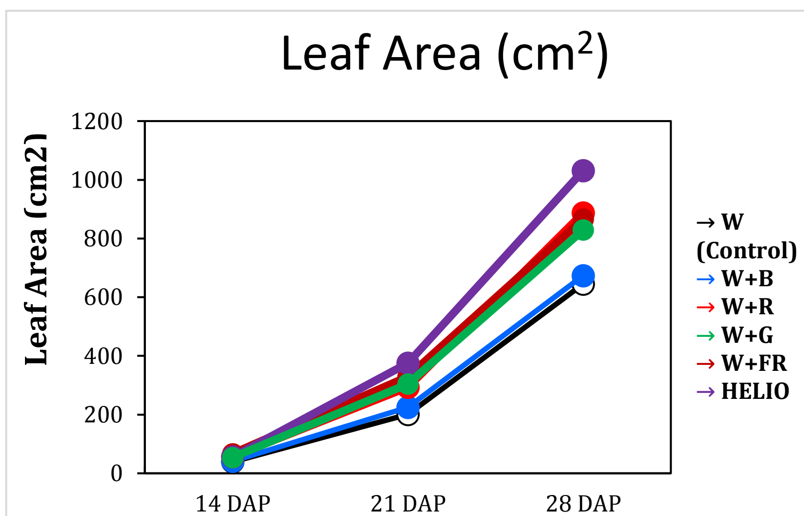


Fig. 2. Leaf area for all treatments for 14, 21,and 28 DAP.

For shoot length, all of the differences with the treatments with the exception of W + B were equally extremely statistically significant (****) from the W (control), ranging from about 234 mm average (W + R) to approximately 256 mm average (Helio) in comparison to the average shoot diameter of about 198 mm for W (control). For shoot diameter, plants grown under W + G, Helio, W + R, and W + FR had a larger shoot diameter, while the W + B treatment showed a reduction in shoot diameter in comparison to the control (Fig 4.). All of the differences with the treatments were extremely significant when comparing to the W (control).

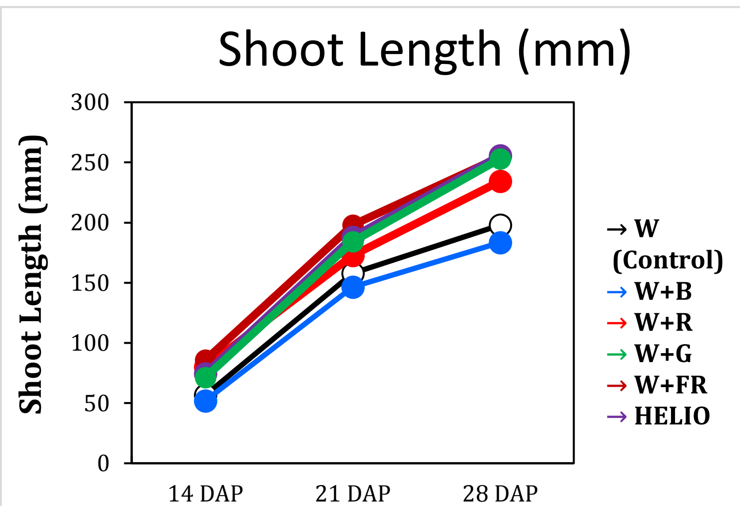


Fig. 3. Shoot length for all treatments for 14, 21,and 28 DAP.

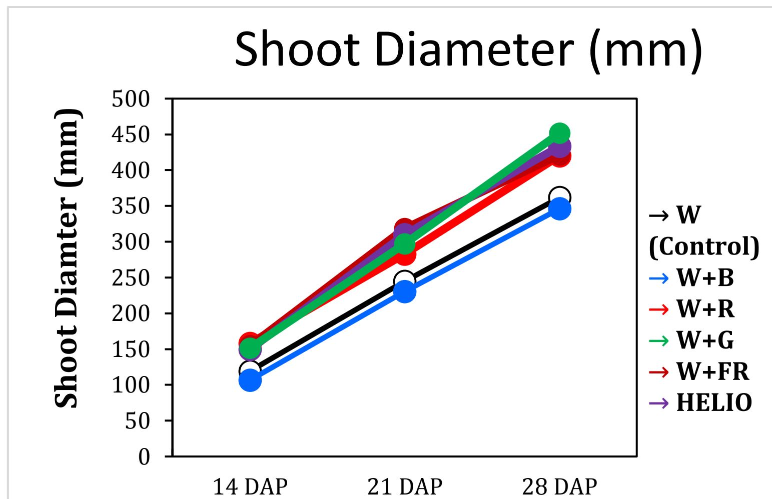


Fig. 4. Shoot diameter for all treatments for 14, 21, and 28 DAP.

Chlorophyll Content Analysis

For the relative chlorophyll tests, the W + B had the largest chlorophyll content at 28 DAP followed by W (control), W + G, W + R, Helio, and W + FR; however, the only treatment showing statistically significant difference as the lowest in chlorophyll content was the W + FR treatment.

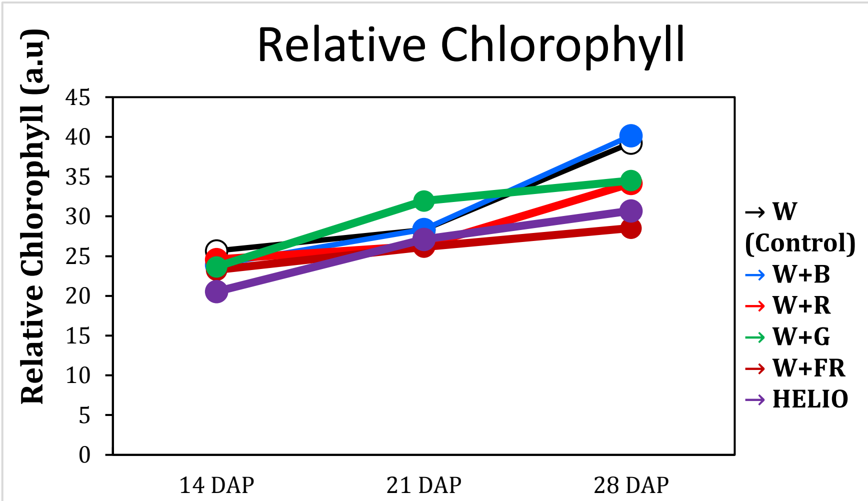
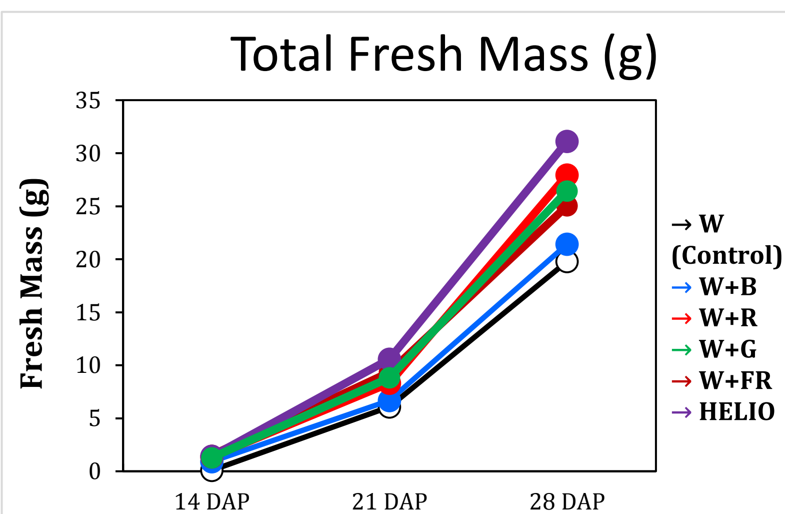


Fig. 5. Relative chlorophyll for all treatments for 14, 21,and 28 DAP.

Biomass Production

At 28 DAP, all treatments with the exception of W + B showed a significant difference in total fresh mass upon comparison with the control, the Helio treatment being the most significantly different ($p < 0.0001$). The difference in total dry mass only reached significant levels in the Helio treatment when comparing to the control at 21 DAP. (The dry mass data for 28 DAP is still in the process of being determined.)



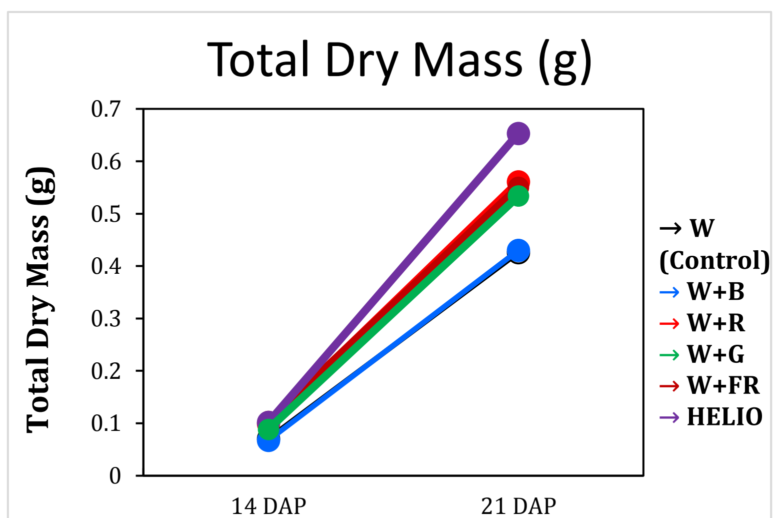


Fig. 6. Total fresh mass for all treatments for 14, 21,and 28 DAP.

Fig. 7. Total dry mass for all treatments for 14 and 21 DAP.

V. Discussion

Other studies have acknowledged that blue and red LEDs have a strong influence on plant morphology (Johkan et al., 2012). Based on the current investigation, the Helio, W + R, W + G, and W + FR treatments all play a large role in affecting plant morphology by increasing the overall plant dimensions in comparison to the W control. The Helio, W + R, W + G, and W + FR treatments all produced significant larger values for shoot length and shoot diameter. It was expected that the Helio, W + R, and W + FR would have greater shoot length because of the phytochrome response activated by red and far red wavelengths (630-745 nm), which are both included in the Helio treatment. A shade avoidance response is triggered and causes stem elongation. The Helio, W + G, and W + FR treatments ended up having larger leaf surface areas while the Helio and W + FR treatments significantly drove greater leaf numbers. The W + B did consistently produce plants with shorter shoot diameters and shoot lengths.

The Helio, W + R, W + G, and W + FR treatments all produced significant larger values for total fresh mass and total dry mass. The dry mass, the amount solely attributed to the carbon accumulated since water is extracted, is important because it shows the total amount of carbon synthesized by the plant via photosynthesis. Results show that these treatments - Helio, W + R, W + G, and W + FR- caused the plants to synthesize more biomass perhaps as a result of being more efficient in the photosynthesis process.

Relative chlorophyll values were determined to be not significantly different among the different treatments with the exception of the W + FR treatment which also has one of the greatest surface areas. Because a plant produces chlorophyll that is distributed within the leaf, a larger leaf area index would result in a dilution effect causing a smaller value of relative chlorophyll. Since the Helio treatment had the largest leaf area but did not have the smallest chlorophyll content, perhaps it had more chlorophyll than the average treatment. However, the W control and W + B treatments did have an increase amount of chlorophyll which makes sense because blue light induces synthesis of anthocyanin and chlorophyll by activating the cryptochrome photoreceptor which is excited by blue light at ~450 nm. Since the white light (control) is composed of 450 nm (blue light) in addition to yellow light, both the white control and the W + B treatments were able to activate this photoreceptor and produce a greater amount of chlorophyll relative to the other treatments.

Other phytochemical analysis is under investigation, but the time of my internship did not allow me to come to any final conclusions regarding these other chemical components. Other phytochemicals being tested for include anthocyanin, carotenoids, lutein and zeaxanthins. Carotenoids and anthocyanin are flavonoids and antioxidants which are important for human health due to their importance in reducing susceptibility to free radicals that could cause cancer, which is especially valuable and helpful for astronauts as they are constantly confronted with cosmic radiation. Since astronauts face a common issue of decreased eye health, lutein and zeaxanthins are quite beneficial as they play an important role in reducing vision loss. More elemental analysis is also being performed, testing for macro and micronutrients such as phosphorous and potassium.

VI. Conclusion

The Helio spectra, bypassing chlorophyll (b) and targeting chlorophyll (a) absorption bands while adding green light, shows some promising results in growing Outredgeous Red Romaine lettuce in controlled ground conditions. Perhaps by further experimenting with these spectra, the efficiency of lighting and plant growth can be perfected to grow an abundant of food supply for astronauts on their journey to Mars.

VII. References

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